APPENDIX MS5. BIOLOGICAL AND ECONOMIC EFFECTS OF CATCH CHANGES DUE TO THE PACIFIC COAST GROUNDFISH INDIVIDUAL QUOTA SYSTEM

Iris A. Gray, Isaac C. Kaplan, Ian G. Taylor, Daniel S. Holland, Jerry Leonard

NOAA Fisheries, Northwest Fisheries Science Center

ABSTRACT

Instituted in 2011, the US West Coast groundfish catch shares program assigns individual groundfish vessels a portion of the quota for target and bycatch species. This new incentive is likely to cap most bycatch, while leading to increases in catch of target species (particularly flatfish) through changes in gear, location and timing of fishing. As part of previous work, Pacific Fishery Management Council staff developed several scenarios for fishery catch under varying assumptions about improvements in targeting accuracy. We investigate the effect of these suggested changes in fishery catch using an Atlantis ecosystem model and an input-output model for Pacific coast fishery economics (IO-PAC). We found that target species in the California current responded directly to the imposed fishing mortality rates. Indirect (trophic) effects were minor and typically involved response of less than 10%. Relative to pre-catch share conditions, the scenarios suggest improved targeting by the groundfish fleet could yield $27-44 million more in revenue to the fishery sectors (dockside value). At the scale of the broader West Coast economy, the economic model suggests this may translate into $22-36 million more in total income, which includes employee compensation and earnings of business owners.

INTRODUCTION

Catch Share Program

In 2011 the Pacific Fishery Management Council instituted a program of individual fishing quotas (catch shares) for groundfish fisheries on the US West Coast(Pacific Fishery Management Council 2010a). The individual fishing quotas allow each vessel a fixed proportion of the annual groundfish quota; full observer coverage and accounting of bycatch is also required. This is a substantial departure from the previous system of two-month landings limits per vessel, with partial observer coverage of the fleet extrapolated to estimate bycatch and discards.

Evidence from other regions suggests that catch shares may improve management performance for target and bycatch species that fall within the individual quota program. Global meta-analyses suggest that individual fishing quotas may reduce the likelihood of fisheries collapse (Costello *et al.* 2008). Experience in British Columbia (Branch *et al.* 2006) and globally (Essington 2009), suggests that individual fishing quotas are likely to decrease discarding, particularly with full observer coverage. Essington (2009) and Melnychuk et al. (2011) have found that the primary effect of catch shares was to decrease variability in three metrics: landings, discard rates, or the ratio of catches to quota. There is also some evidence from US and international case studies (Branch 2009) that individual fishing quotas will promote stewardship , in terms of fishers requesting cuts to total catch. On the other hand, individual fishing quotas do not necessarily lead to improved status of non-target species (those outside the quota system) or ecosystem metrics (Gibbs 2010), and they have long been criticized for potential impacts on allocation, fleet consolidation, and economic and social equitability (McCay 1995).

Though individual fishing quotas have been in place for a full year for US West Coast groundfish fisheries, the long term consequences of this policy shift are not yet clear. This is due both to the evolution and learning that is inherent to fishing operations, and the phased implementation of catch shares. Analysis of preliminary data suggests that in 2011 fishers focused on sablefish and deeper water species, leaving a high proportion of rockfish (*Sebastes* spp.) and flatfish quotas unharvested. Depleted rockfish stocks have very low quotas, and potential for high bycatch of rockfish (particularly in shallower areas) may have constrained the ability of the fleets to fully harvest quotas of other target stocks. For example, only a small proportion of quotas of some valuable shelf species such as chilipepper rockfish and lingcod species were caught in 2011, likely due in part to individual captains' concerns about exceeding bycatch caps for several overfished rockfish species and halibut. Additionally, there is limited market demand for flatfish such as Dover sole and arrowtooth flounder, further discouraging targeting of these species. Dover sole is a potentially very large fishery, but in recent years catches have been less than half of total quotas. Total catches of potentially constraining rockfish species were only a small fraction of total quotas in 2011.

Catches of several important target species could be increased substantially depending on future demand and the ability of captains to keep rockfish catches below bycatch caps. Over time, fishermen may become less risk averse if they become more confident that they can acquire more quota to cover unexpected bycatch, and we might expect to see increases in catches of both target and bycatch species. Conversations with experts as part of an informal scoping exercise (Engagement section) suggest that fishers are planning or undertaking experiments with gear and fishing areas, in an effort to more precisely harvest target stocks while avoiding particular rockfish species. However, failure to fully exploit quotas of many species may also be due to economic reasons – e.g., lack of demand. For these species catches may increase only if prices increase as a result of increased global demand for fish and development of new markets. Finally, phased implementation of the catch share program involves a two year moratorium on sale of quota, with leasing only during this period (Pacific Fishery Management Council 2010a); quota sales could also change the long-term incentives towards more focused targeting, specialization, and marketing efforts for stocks that were not fully harvested in 2011.

Here we investigate the potential ecological and economic effects of catch changes due to individual fishing quotas for US West Coast groundfish. By coupling an Atlantis ecosystem model (Horne *et al.* 2010; Kaplan *et al.* 2012) with an economic input/output model (Leonard and Watson 2011), we project the economic effects for 1-15 years, and the ecological effects for 1-25 years. Ecosystem dynamics are driven by four scenarios for catches (total mortality) of groundfish species, derived by the Pacific Fishery Management Council (2010b) as part of the environmental impacts statement for the individual quota system. We categorize these three scenarios as *slightly optimistic*, *more optimistic*, and *highly optimistic*, in terms of the ability of vessels to fully harvest the quota of all stocks. We also test a scenario ("*prior to catch shares*") that represents harvests in 2007, before catch shares were implemented, and likely before any fishing activity that anticipated catch shares. The focus of the harvest increases is directed primarily at Dover sole. Other species catches projected to increase under these various levels of optimism include Arrowtooth flounder (*Atheresthes stomias*), other flatfish (mostly Rex sole, *Glyptocephalus zachirus*, and Pacific sanddab, *Citharichthys sordidus*), Shortspine thornyhead (*Sebastolobus alascanus*), Chilipepper rockfish (*Sebastes goodei*), Yellowtail rockfish (*Sebastes flavidus*), Longspine thornyhead (*Sebastolobus altivelis*), and Lingcod (*Ophiodon elongatus*). These species may experience increases in catch because they are currently harvested at levels well below the quotas; increased harvest could result from direct harvesting or incidental bycatch. These scenarios for catches (Pacific Fishery Management Council 2010b) do not specify the exact changes in fishing techniques or seafood demand that would facilitate these scenarios. Conversations with an industry representative and managers (Engagement section) suggest that they would likely involve changes in fishing practices, areas fished, or marketing opportunities for low-valued flatfish.

The ecosystem model evaluates both direct (harvest) effects and indirect (food web) effects related to these catch scenarios. We consider the impact on the full food web. Below, we compare Atlantis projections to predictions from single-species stock assessment models for a very limited set of species. The economic input-output modeling allows us to translate Atlantis output, in terms of fishery revenue, to the impact on income in the broader US West Coast economy.

METHODS

Atlantis Model

The Atlantis marine ecosystem model simulates the food web and fisheries in the California Current (Horne *et al.* 2010; Kaplan *et al.* 2012). The model is spatially explicit, and is forced by salinity, temperature, and currents driven by a Regional Ocean Modeling System (ROMS). Functional forms and data for the California Current are described in Brand et al. (2007), Horne et al. (2010), and Dufault et al. (2009); additional core equations are described in Fulton (2001, 2004). The Atlantis code base and recent applications have been summarized by Fulton et al. (2011). Additional information is available from http://atlantis.cmar.csiro.au/ ; its application by NOAA to issues in the US and Mexico is described here: http://www.nwfsc.noaa.gov/publications/documents/atlantis_ecosystem_model.pdf . As part of the 2011 Integrated Ecosystem Assessment, this version of the model was used to screen management scenarios related to gear shifts and spatial management (Kaplan *et al.* 2011). Additionally, those management scenarios were linked to economic impacts (employment and income) by Kaplan and Leonard (Kaplan and Leonard 2012), using an approach similar to the one here.

The "*prior to catch shares"* scenario has catches of groundfish and non-groundfish fleets that match 2007 harvests, including discards where such information is available. A description of the fleets (based on gear type) and harvests under this base scenario is described elsewhere (Kaplan *et al.* 2012; Kaplan and Leonard 2012). All scenarios involved 50 year simulations of the biology, constant harvest rates (%yr^{-1}) with no additional management intervention (such as closed areas or quota reductions) , and applications of the economic model to years 1- 15.

The three alternate scenarios *(slightly optimistic, more optimistic, and highly optimistic*) scale these fishing mortality rates by multipliers taken from Pacific Fishery Management Council (2010b). We calculated these multipliers as the ratio of catch per scenario divided by catch under pre-catch shares scenario. These multipliers can be found in Table 1.

Name in Pacific Fishery Management Council (2010b)	**Atlantis Functional Group**	**Prior to Catch Shares**	**Slightly Optimistic**	**More Optimistic**	**Highly Optimistic**
Chilipepper, Yellowtail	Midwater rockfish	1.00	1.00	3.51	4.02
Shortspine, ½ Slope rockfish	Deep large rockfish	1.00	2.02	2.23	2.23

Longspine, ½ Slope rockfish	Deep small rockfish	1.00	2.54	2.77	2.77
Sablefish	Sablefish	1.00	1.00	1.00	1.00
Dover sole	Dover sole	1.00	1.85	1.85	2.54
Arrowtooth, Petrale	Large piscivorous flatfish	1.00	1.38	1.38	1.38
Other flatfish	Small flatfish	1.00	2.03	3.18	3.18
Dogfish shark	Small demersal sharks	1.00	1.00	1.00	1.00
Pacific hake	Pacific hake	1.00	1.00	1.00	1.00
Lingcod	Lingcod	1.00	1.00	1.21	1.49

Table 1. Multipliers used to increase the fishing mortality rates for groundfish. The leftmost columns illustrate how we matched species groups reported in an environmental impact statement (Pacific Fishery Management Council 2010b) to our Atlantis model functional groups. Fifty percent of the "Slope rockfish" group from the EIS was assigned to the Atlantis deep large rockfish group, and fifty percent to the deep small rockfish group.

IO-PAC Model

We applied an input-output model for Pacific Coast Fisheries (IO-PAC, Leonard and Watson (2011)) to predict how changes in the fishery sector's revenue would affect income at the scale of the US West Coast(Leonard and Watson, 2011). Note that revenue signifies dockside value (ex-vessel value), while income refers to employee compensation and profits to business owners. Income effects involve both direct effects (to employees and businesses in the fisheries sector), indirect effects (e.g. to shipyards or fuel suppliers), and induced effects through changes in total household spending along the US West Coast. The goal was to broaden the focus beyond the fisheries sector, to the entire West Coast economy.

The methodology follows Kaplan and Leonard (2012). We first calculate total revenue from the fisheries (large groundfish trawler, non-nearshore fixed gear, and shoreside hake midwater trawl), seafood processors, and wholesalers. We then apply IO-PAC to predict income effects 1, 5, 10, and 15 years into the future. Revenue represents all money coming into only the fishing sector (dockside or ex-vessel value of fish, and gross receipts of seafood processors and wholesalers), while income is calculated from IO-PAC at the scale of the entire West Coast economy. Effects of any fishery sector on the west coast economy include direct effects (income by the fishery sector), indirect effects (income by supporting industries such as shipyards), and induced effects (income effects through coastwide changes in household spending). Though the biological model projects beyond 15 years, we do not apply IO-PAC beyond year 15, due to its assumptions regarding constant prices, costs, and fixed units of inputs required per unit of output. Dockside value of landed seafood is fixed at 2006 prices. We do not report employment changes due to the high uncertainty regarding fleet consolidation under catch shares (Lian *et al.* 2010)and resulting changes in employment in the fishing sectors. In reality, if consolidation occurs this may also modify costs and inputs (e.g. diesel, ice) required by seafood sectors, but for simplicity we hold these at constant values based on data collected prior to implementation of catch shares.

Revenue Comparison between Atlantis and Environmental Impact Statement (Pacific Fishery Management Council 2010b)

Comparable to our Atlantis predictions of harvests under these four scenarios, the Pacific Fishery Management Council (2010b) provides predictions of harvest per scenario. Both predictions for year 1 harvest were converted to revenue :

$$R = 2204.62 \cdot P \cdot C \cdot (1 - D)$$

Where R is revenue per species in dollars, P is the price per pound of the species (in 2006), C is the total catch in metric tons, and D is the discard ratio (Bellman 2008). The coefficient 2204.62 is the number of pounds in a metric ton. Note that since the Atlantis year 1 harvests were calibrated to match the *prior to catch shares scenario* harvests, we expect the Atlantis harvests under other scenarios to differ only slightly from PFMC 2010b harvests, due to ecological dynamics and different groupings of species (e.g. Atlantis functional groups versus PFMC 2010b aggregation at the level of species or “slope rockfish” and “shelf rockfish”).

We provide this simple comparison to illustrate that fishery sector revenue estimates are similar whether taken from the Atlantis ecosystem model or simpler predictions from the PFMC (2010b) environmental impact statement. Since IO-PAC predictions of income are simple multipliers of revenue, income is also comparable whether predicted using Atlantis or from the environmental impact statement.

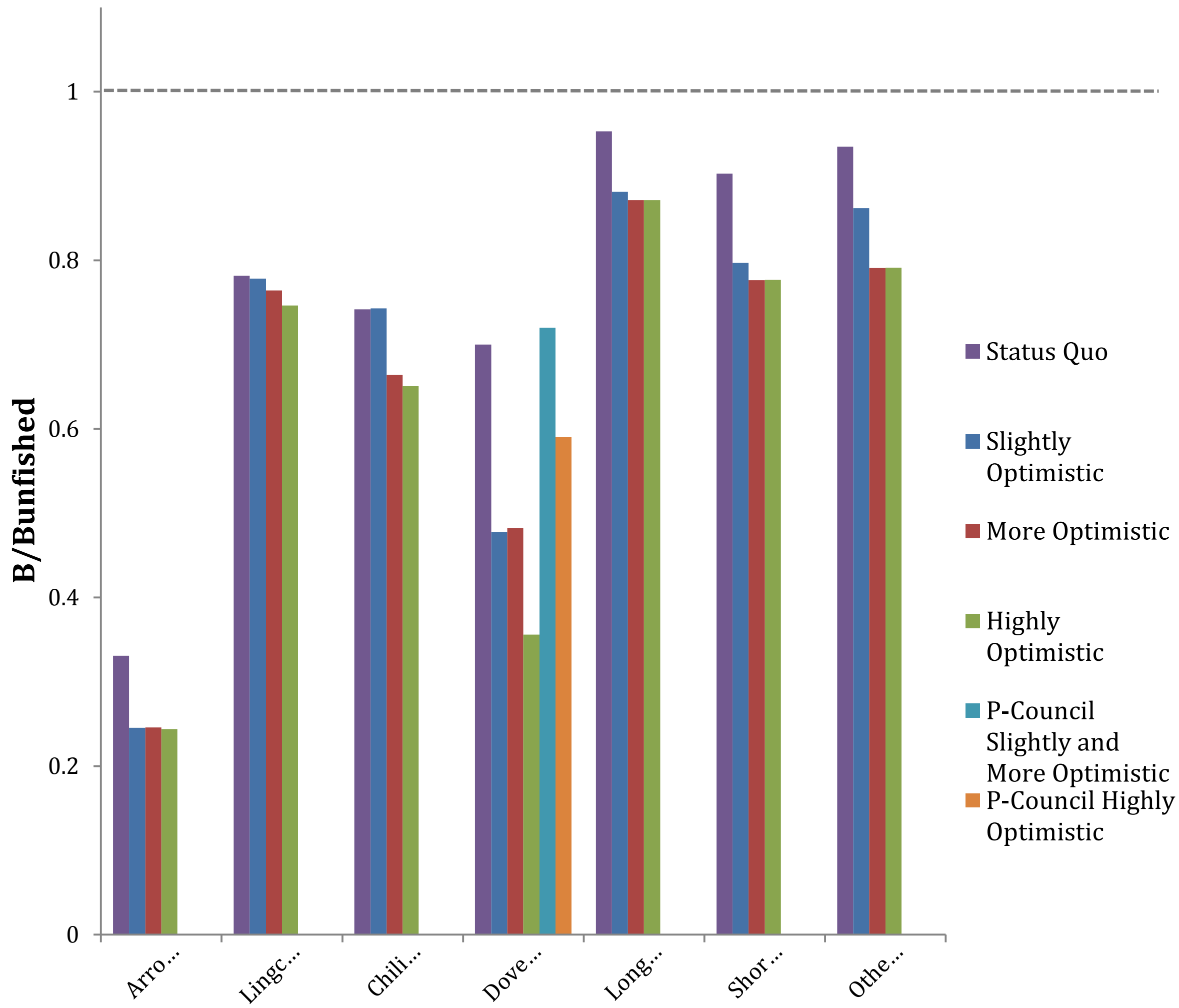

Figure 1. Relative biomass at year 25 predicted by the Atlantis ecosystem model. Also included for comparison are year 25 relative biomass values of Dover sole from a single species stock assessment (Pacific Fishery Management Council 2010b). All other functional groups varied less than 5% among scenarios.

RESULTS

Biological effects on targeted groundfish

Biomass of targeted groundfish that were the focus of the increased fishing effort decreased (Figure 1) due to direct increases in harvest rate (Figure 2). For example, harvest rate for lingcod was low (<2.5%) in the *prior to catch shares* scenario and remained low in all scenarios, which resulted in small comparative reductions in lingcod biomass over the three scenarios. By contrast, harvest rate of Dover sole increased more over the three scenarios than it did for other species, and thus Dover sole had the greatest decrease in biomass, roughly a halving of abundance at year 25. (In all scenarios Dover sole abundance remained above the current management target, 25% of unfished spawning biomass, through year 25.) Longspine thornyhead (deep small rockfish), shortspine thornyhead (deep large rockfish), arrowtooth (large piscivorous flatfish), other flatfish, and chilipepper and yellowtail rockfish experienced lesser increases in fishing mortality, and resulting biomass reductions of 14% or less. Single-species projections from a stock assessment model also predicted that Dover sole would decline under the *highly optimistic scenario* (PFMC 2010b), but by only about 20% (Figure 2).

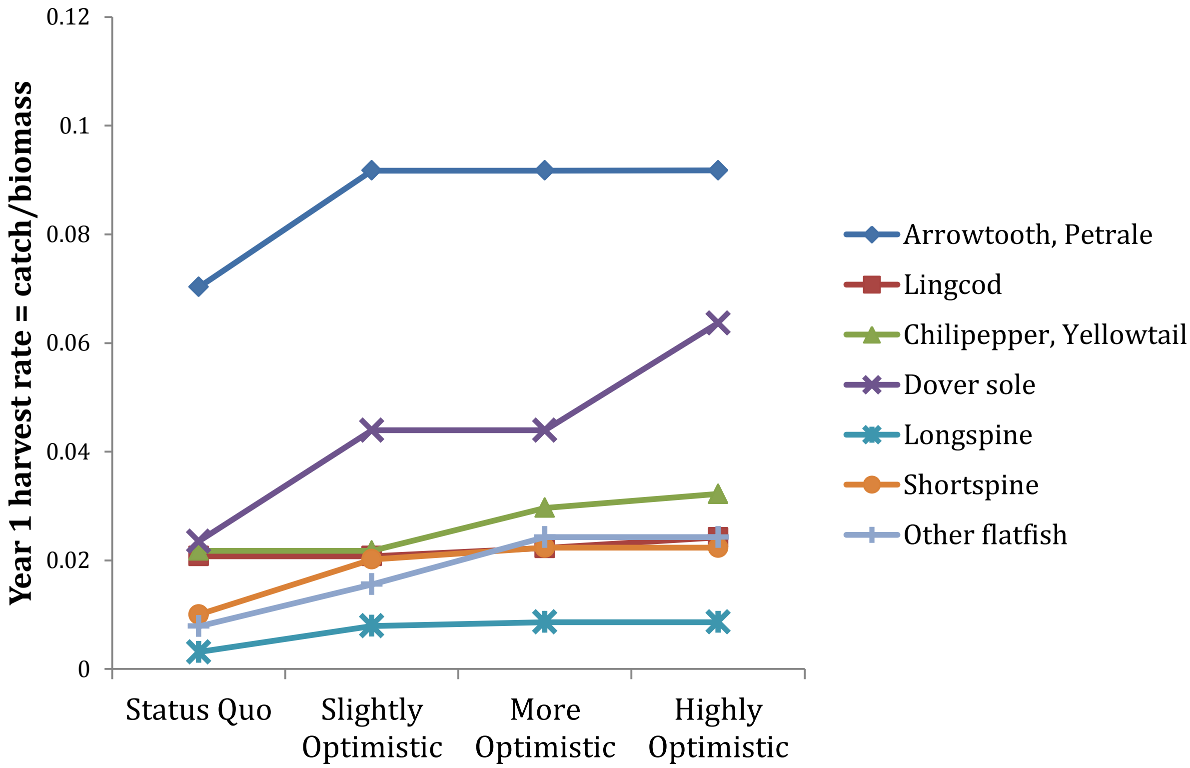

Figure 2. Harvest rate (calculated as harvest rate =catch/biomass) for each species or functional grouper, per scenario.

Trophic Effects

Indirect trophic effects of the catch share scenarios were minor. Functional groups that were not subject to increased fishing pressure in the catch share scenarios did not deviate more than 10% from status quo. The direct reduction in flatfish and some rockfish biomass led to slight reductions in predation pressure on bivalves, shrimp, and mesozooplankton. In the most extreme case (*highly optimistic scenario*, year 50) these species groups increased in biomass by 3%, 2.5%, and 6%, respectively. Predators on these invertebrates increased in abundance — mackerel by 9%, sculpin by 3%, and small shallow rockfish by 3% (a group mostly composed of stripetail and greenstriped rockfish). Pelagic sharks are heavily dependent on mackerel as prey, and therefore exhibited a comparable increase in biomass (8%).

Economic Effects

Relative to the *prior to catch shares scenario*, all other scenarios resulted in increased revenue for fishing sectors, and related increases in total income in the broader west coast economy. However, two of the three gears exhibited little or no increase to their revenue (Table 2). The non-nearshore fixed gear fleet (longline and pot) exhibited only a 6-9% increase in revenue. This might be expected *a priori*, as this gear catches little Dover sole, and the primary target species (sablefish) for this fleet is currently harvested at close to the allowable quota. The shoreside hake fleets had no increase in revenue, since hake catches were not projected to increase (Table 1) and species other than hake that are caught by this fleet are typically discarded at sea or at the processor (V. Tuttle, NWFSC, pers. comm.). Large groundfish trawlers had markedly higher increases in revenue (34 – 72% across all scenarios and years, Table 2). This gear often targets Dover sole and other species slated for harvest increases in our scenarios.

The increase in revenue for groundfish trawlers under the catch share scenarios led to equivalent increases in terms of that fleet's contributions (direct, indirect, and induced) to coastwide total income in the first year of the most optimistic scenario (Figure 3). High fishing mortality rates (under the most optimistic scenarios) had the largest catches early in the simulations; by year 15 high fishing mortality rates caused declines in biomass, and reduced the differences between catch (or revenue) under catch shares versus the *prior to catch shares* scenario (Table 2).

Revenue				
		Percent increase relative to *Prior to catch shares scenario*		
Gear	**Year**	***Slightly optimistic***	***More optimistic***	***Highly optimistic***
Large Groundfish Trawler	1	47	55	72
	5	42	51	64
	10	36	45	53
	15	34	40	46
Non-nearshore Fixed	1	7	9	9

Gear	5	6	8	8
	10	6	7	8
	15	6	8	8
Shoreside Hake Midwater Trawl	1	0	0	0
	5	0	0	0
	10	0	0	0
	15	0	0	0
Processor	1	28	32	42
	5	25	30	38
	10	22	28	33
	15	22	26	30
Wholesaler	1	28	32	42
	5	25	30	38
	10	22	28	33
	15	22	26	30
Total	1	28	32	42
	5	25	30	38
	10	22	28	33
	15	22	26	30

Table 2. Percent increase of revenue due to the effects of catch share scenarios, compared to the prior to catch shares scenario prediction for the same year. The color scheme highlights maximum (green) and minimum (red) changes. Proportional increases in income effects are identical to revenue (within 1%), since these scale linearly with revenue. We assume constant prices for seafood over the 15 years.

Overall, if fleets can increase harvests of flatfish and some rockfish to the levels suggested for the *most optimistic scenario*, fishery sector revenue will be approximately $141.7 million, with $118.8 million in income effects in the first year of implementation (Figure 3). This is approximately 40% above the *prior to catch share scenario* values of $100 million in revenue and $84 million in income effects.

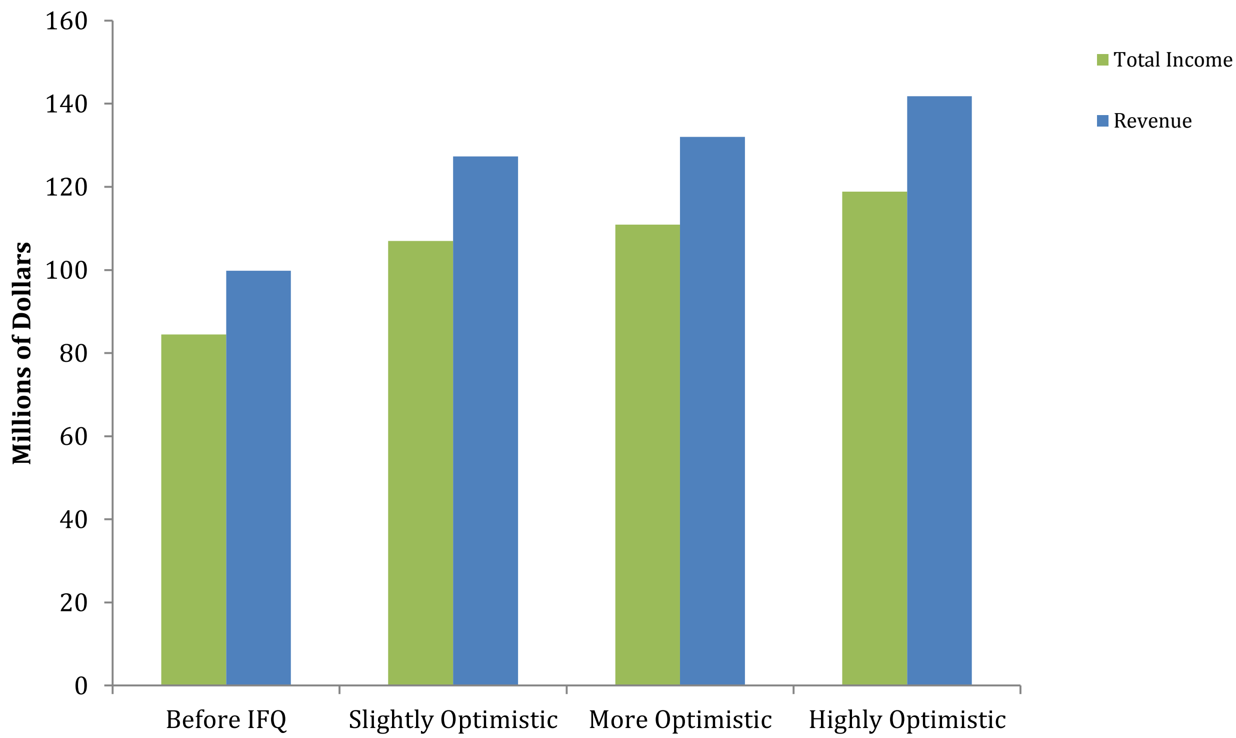

Figure 3. Revenue in fishery sectors, and income effects in the broader West Coast economy. Year 1 predictions. Total income and revenue are represented by bars in millions of dollars (left axis).

Revenue Comparison between Atlantis and Environmental Impact Statement (Pacific Fishery Management Council 2010b)

Focusing only on year 1 revenue from the three fishing fleets, catches from scenarios listed in PFMC (2010b) equate to revenue of $77 million, $90 million, $95 million, and $99 million for the four scenarios (ranging from *prior to catch shares* to *highly optimistic*). Catches from Atlantis translate into revenues of $66 million, $81 million, $85 million and $90 million, respectively. In relative terms, the year 1 PFMC (2010b) catches for the *highly optimistic scenario* have revenues 29% higher than *prior to catch shares*, while Atlantis predicts revenues 40% higher than *prior to catch shares*. The $9-10 million difference between Atlantis and direct application of the PFMC (2010b) is due primarily to the aggregation of species into functional groups for Atlantis; each functional group must have a single (dockside) price, rather than species-level prices that we applied to the PFMC (2010b) catches. Thus, for example, petrale sole (a valuable flatfish), is grouped with arrowtooth flounder (a low-value species with little market demand).

DISCUSSION: A TALL ORDER, TWO STEPS AT A TIME

The California Current IEA aims to evaluate the potential ecological, economic, and social impacts of management actions and future drivers such as climate change. This is a formidable task. Explicitly linking pressures (e.g. land-based pollution) to responses (e.g. status of protected species) is not always possible with the current generation of models and scientific knowledge; explicitly linking drivers (e.g. human population growth) to pressures is perhaps best handled by a challenging blend of demographic or climate forecasting and formal scenario planning exercises (e.g. Millennium Ecosystem Assessment (2005)). However, given the scope of the IEA and the drivers, pressures, and responses of interest (Figure 4**)**, we can begin to make linkages where the scientific capacity exists. Moreover, by linking published approaches and methodologies, for particular questions we can move two steps at a time, for instance forecasting both ecological impacts and impacts on human communities.

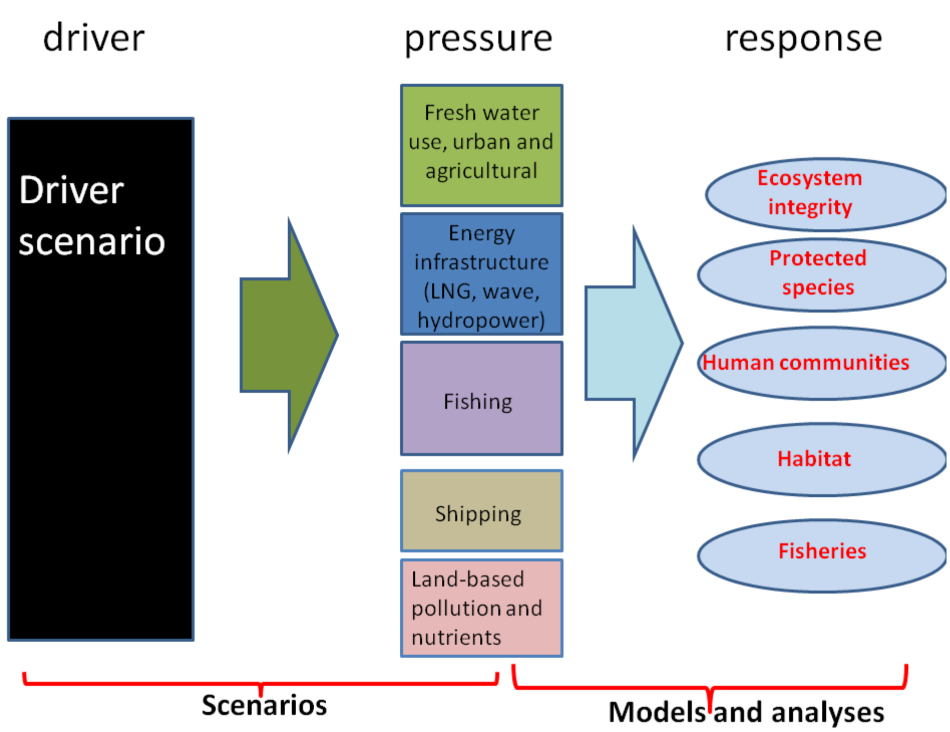

Figure 4. Schematic of Management Testing approach, where drivers are linked to pressures via narrative scenarios, and then quantitative models link pressures to responses.

Of 16 managers, stakeholders, and scientists who identified drivers and pressures relevant to the California Current, eight commented on the potential ecological and economic impacts of the new groundfish catch share program (Engagement section). Our work here addresses those questions, using two quantitative models to forecast those effects at relevant temporal scales: 1-25 years for biological variables, and 1-15 years for economic values. The Atlantis ecosystem model identifies some minor trophic effects of potential catch share scenarios, but overall suggests that major effects will only occur for fishery target species. The economic IO-PAC model predicts up to 40% increase in income effects by the seafood sectors on the broader West Coast economy, with most of this increase deriving from groundfish trawl revenue. The results can also inform future analyses related to human social wellbeing, such as those by Jacob et al (2012) that can include predictors such as fishery landings and household income.

The models here capture only some of the salient characteristics of the ecosystem, fisheries, and economy, and results should be considered strategic and comparative, rather than definitive and precise. This application of the Atlantis ecosystem model uses coarse functional groups of aggregated species, it assumes smooth recruitment relationships, and it focuses on the groundfish community rather than pelagic species. The fisheries are implemented with constant fishing harvest rates, rather than with a dynamic management response that adjusts harvest rates as biomass varies. The IO-PAC model assumes fixed costs, price, and inputs per unit of output; critically this means that all innovation and learning must be captured in the catch scenarios defined by PFMC (2010b). Other efforts are needed to capture more fine-scale fleet behavior and economic responses to catch shares (Kaplan et al, AppendixMS6), and to predict long-term economic impacts to the region (Finnoff and Tschirhart 2003). Appropriate application of such strategic models is discussed in Fulton et al. (2011), in particular for ranking management strategies and identifying the relative impacts of threats and pressures. Our results here are strengthened by a comparison to single species stock assessment for Dover sole, and simple revenue calculations that directly expand from PSMFC (2010b). This type of multi-model inference is necessary and appropriate as new models are developed that address drivers and pressures beyond simply fishing.

Though this application focused on direct fishing mortality effects for groundfish, both the Atlantis and IO-PAC frameworks are being expanded to address new drivers, pressures, and ecosystem components. This includes Atlantis forecasts related to climate change and ocean acidification, and regionalized IO-PAC applications that include fleets that harvest salmon and Dungeness crab. Both salmon and crab may be more likely than groundfish to be impacted by global change. Analyses using these tools and others can be used to screen a broad range of management scenarios and climate drivers.

REFERENCES

Branch, T.A. (2009) How do individual transferable quotas affect marine ecosystems? *Fish and Fisheries* **10**, 39–57.

Branch, T.A., Rutherford, K. and Hilborn, R. (2006) Replacing trip limits with individual transferable quotas: implications for discarding. *Marine Policy* **30**, 281–292.

Brand, E.J., Kaplan, I.C., Harvey, C.J., Levin, P.S., Fulton, E.A., Hermann, A.J. and Field, J.C. (2007) A Spatially Explicit Ecosystem Model of the California Current's Food Web and Oceanography. *NOAA Technical Memorandum* **NMFS-NWFSC-84**.

Costello, C., Gaines, S.D. and Lynham, J. (2008) Can Catch Shares Prevent Fisheries Collapse? *Science* **321**, 1678–1681.

Dufault, A.M., Marshall, K. and Kaplan, I.C. (2009) A synthesis of diets and trophic overlap of marine species in the California Current. *NOAA Technical Memorandum* **NMFS-NWSC-103**.

Essington, T.E. (2009) Ecological indicators display reduced variation in North American catch share fisheries. *Proceedings of the National Academy of Sciences* **107**, 754–759.

Finnoff, D. and Tschirhart, J. (2003) Harvesting in an eight-species ecosystem. *Journal of Environmental Economics and Management* **45**, 589–611.

Fulton, E. (2004) Biogeochemical marine ecosystem models II: the effect of physiological detail on model performance. *Ecological Modelling* **173**, 371–406.

Fulton, E.A. (2001) The effects of model structure and complexity on the behaviour and performance of marine ecosystem models.

Fulton, E.A., Link, J.S., Kaplan, I.C., *et al.* (2011) Lessons in modelling and management of marine ecosystems: the Atlantis experience. *Fish and Fisheries* **12**, 171–188.

Gibbs, M.T. (2010) Why ITQs on target species are inefficient at achieving ecosystem based fisheries management outcomes. *Marine Policy* **34**, 708–709.

Horne, P.J., Kaplan, I.C., Marshall, K.N., Levin, P.S., Harvey, C.J., Hermann, A.J. and Fulton, E.A. (2010) Design and Parameterization of a Spatially Explicit Ecosystem Model of the Central California Current. *NOAA Technical Memorandum* **NMFS-NWFSC-104**, 1–140.

Jacob, S., Weeks, P., Blount, B. and Jepson, M. (2012) Development and evaluation of social indicators of vulnerability and resiliency for fishing communities in the Gulf of Mexico. *Marine Policy*.

Kaplan, I.C., Horne, P.J. and Levin, P.S. (2011) Influence of Some Fisheries Management Options on Trade-offs between Groundfish and Ecosystem Health Objectives. In: *NOAA Technical Memorandum*, Vol. NMFS-NWSC-109. *NOAA Technical Memorandum*. NMFS-NWSC-109, pp 142–182.

Kaplan, I.C., Horne, P.J. and Levin, P.S. (2012) Screening California Current Fishery Management Scenarios using the Atlantis End-to-End Ecosystem Model. *Progress In Oceanography*.

Kaplan, I.C. and Leonard, J. (2012) From krill to convenience stores: Forecasting the economic and ecological effects of fisheries management on the US West Coast. *Marine Policy* **36**, 947–954.

Leonard, J. and Watson, P. (2011) Description of the input-output model for Pacific Coast Fisheries (IOPAC). *NOAA Technical Memorandum* **NMFS-NWFSC-111**, 1–64.

Lian, C., Singh, R. and Weninger, Q. (2010) Fleet Restructuring, Rent Generation, and the Design of Fishing Quota Programs: Empirical Evidence from the Pacific Coast Groundfish Fishery. *Marine Resource Economics* **24**.

McCay, B.J. (1995) Social and ecological implications of ITQs: an overview. *Ocean and Coastal Management* **28**, 3–22.

Melnychuk, M.C., Essington, T.E., Branch, T.A., *et al.* (2011) Can catch share fisheries better track management targets? *Fish and Fisheries*, no–no.

Millenium Ecosystem Assessment (2005) *Ecosystems and human well-being: general synthesis*, (Millenium Ecosystem Assessment, Vol. Ecosystems and Human Well Being). Island Press, Washington, DC.

Pacific Fishery Management Council (2010a) Groundfish Fishery Management Plan Amendment 20 (Trawl Rationalization).

Pacific Fishery Management Council (2010b) Groundfish Fishery Management Plan Amendment 20 (Trawl Rationalization): Chapter 4-- Effects of the Alternatives.